The Electronic Structure and Optical Properties of Phosphorus Implanted GaN films

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We studied photoluminescence (PL), photoluminescence excitation (PLE), Raman spectra of epitaxial GaN layers grown by MOCVD which are implanted by isoelectronic impurities of phosphorus (P) with different doses from ~10^{14} to ~10^{16} cm^{-2}. The P- implanted samples were treated by rapid thermal annealing (RTA) at temperature of 1100℃ with different duration using proximity cap method to recover implantation damages under flowing N_2. The PL spectra of GaN：P shows strong emission peaked around 430 nm with oscillations due to the microcavity effect.[1] (shown in Fig 1) This band is due to the recombination of bound exciton to P-hole isoelectronic traps (P-BE)[2,3]. We also measured thermal quenching of PL spectra and obtained, from the Arrhenius plot of temperature dependent in intensity, the binding energy for exciton localized at the P-isoelectronic trap to be 180 meV.

The low temperature PL spectra of as-implanted samples showed the dominant YL and another broadband located at 467 nm (shown in Fig 2). According to the two different first-principles total-energy calculations [4,5], the implantation likely induces N_I and P-related defects. The N_I is a single, deep acceptor at approximately E_V + 1.0 eV. By comparing the emission of I_2 (D^0, X) with the PLE profile probed at YL band, we found that the absorption edge of the PLE profile almost coincides with the I_2 emission (shown in Fig 3). This indicates that the absorption by band to band and shallow donors enhances the YL. Guénaud et al., suggested that the free exciton absorption contributes to both I_2 and YL emissions while the free electron-hole pairs preferentially promotes YL than I_2.[6] As shows in Fig 4, the incorporation of P has induced localized states that not only increase the YL but also suppress the transition from the free electron-hole pairs to the deep-levels associated to the YL. RTA can recover the damage and help the substitution of P at nitrogen site. We believe that part of I_2 emission can be reabsorbed in the bulk to promote the YL.

Reference

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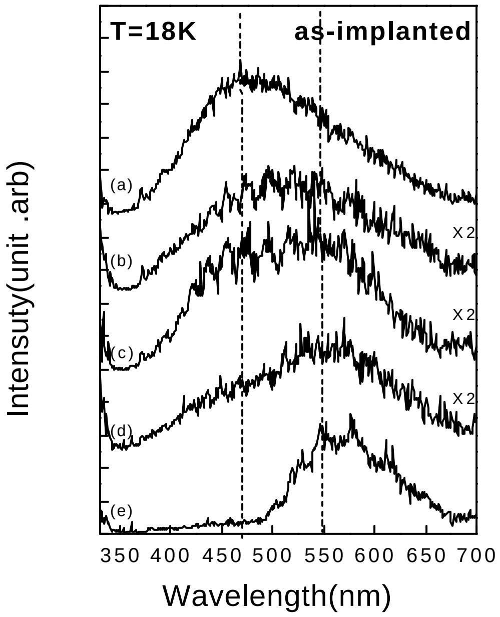

Fig 1. Low temperature PL spectra of as-implanted samples with different doses, (a)10^{16} cm^{-2}, (b)5×10^{15} cm^{-2}, (c)10^{15} cm^{-2}, (d)5×10^{14} cm^{-2}, (e)10^{14} cm^{-2}. The band intensity below 500 nm increases with the P-related dose concentration.

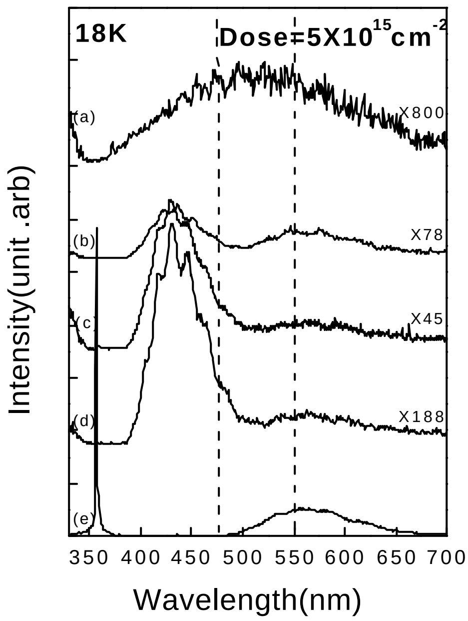

Fig 2. Low temperature PL spectra of P-implanted GaN. The spectra were normalized to YL. (a)as-implanted, (b)RTA 10 sec, (c)RTA 20 sec, (d)RTA 30 sec, (e)as-grown. After RTA , the intensity ratio of P-BE about 430 nm to YL increases with the annealing time. It shows the renormalization of P-related band.

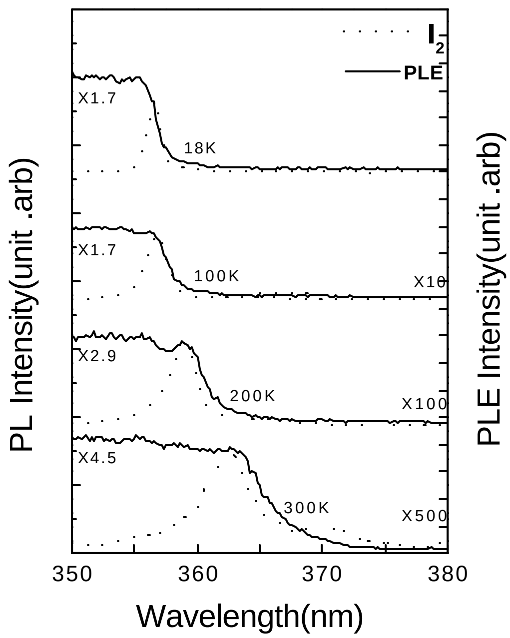

Fig 3. The temperature dependent PLE profiles probed at YL compare with the I_2 line in as-grown samples.

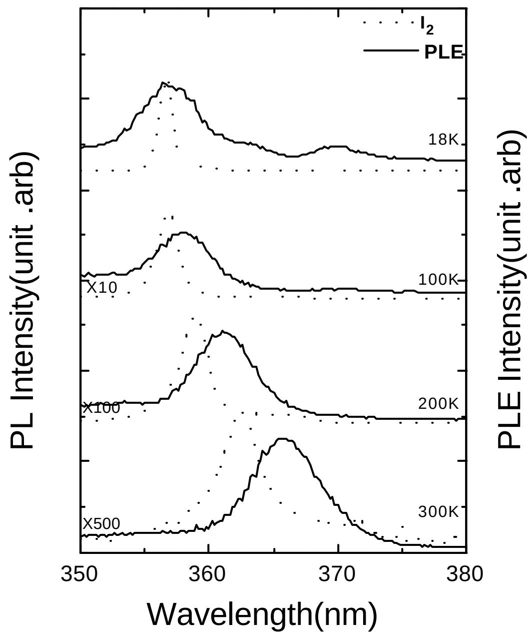

Fig 4. The temperature dependent PLE profiles probed at YL in P-implanted samples after RTA compare with the I_2 PL profiles in as-grown samples.